

WYLE LABORATORIES - RESEARCH STAFF

FINAL SUMMARY REPORT

CONTRACT NO. NAS 8-11312

INVESTIGATION OF NOISE GENERATING MECHANISMS  
OF DEFLECTED AND UNDEFLECTED SUPERSONIC ROCKET EXHAUSTS 4

FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GEORGE C. MARSHALL SPACE FLIGHT CENTER

HUNTSVILLE, ALABAMA

ATTENTION PR-EC

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## 1.0 INTRODUCTION

This contract is for the analytical definition of the physical characteristics of the noise environment created by space vehicles immediately prior to and subsequent to launch. As such, it consists of a number of related tasks concerning the basic mechanism of aerodynamic noise production of high speed jets and the way the sound is radiated including both near and far field effects. Other tasks are motivated by the necessity to develop instrumentation.

### HIGH SPEED JET FLOW PROPERTIES

Wyle Laboratories proposed and designed a series of basic experiments to make measurements of the mixing flow of high speed heated helium jets simulating rocket flow. The prime experiment involved flowing heated helium through three perfect expansion nozzles to give flow exit speeds at Mach 2.6, 3.0, and 3.5. The helium gas is heated to 1100°F to allow the exit properties to approximately equal a typical rocket exhaust except for temperature. Gas density, velocity, Mach number and heat content are all approximately equaled. The lower temperature allows instruments to be placed in the flow to make measurements of the mixing flow, and especially the mixing region surrounding the initial flow region near the nozzle exit.

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The experimental program has three basic phases:

- a) Mean values of the flow parameters, including temperature, velocity and composition.
- b) Fluctuating values of the flow parameters.
- c) Acoustic measurements of the noise radiated by the flow.

The future part of the program is concerned with measurements of the flow of clustered and deflected jet flows.

Marshall Space Flight Center, Aero-Astrodynamic Laboratory, have begun to construct a facility for flowing hot heated gas flows, and have begun preparation for the heated helium tests. The instruments for the mean flow measurements have been completed, and the data acquisition system is virtually complete. The helium heater has been delayed by construction problems, and, in view of past performance and estimates by Fuel Engineering Company, who are building the heater, no firm predictions can be made for when it will be ready.

The program for the mean parameter measurements has been prepared by Wyle Laboratories Research Staff. A review of possible instrumentation systems for the fluctuating component measurements has been completed. Only preliminary design has been attempted on the later experiments.

During the design and construction of the facility, Wyle personnel have been available and have helped in determining the optimum arrangement and details of the rig. Reviews of the drawings and calculations used in the design of the rig, including the nozzles and special instrumentation, have been made at all periods during the construction of the facility.

The following reports have been issued on this task:

- TM 65-3 "Experimental Program for Model Jet", (1965).
- TM 65-12 "A Note on the Acoustic Environment in the Helium Heater Building, MSFC", (1965).
- TM 66-21 "A Review of Proposed Control and Instrument Room for Building 4776, MSFC, Huntsville, Alabama", (1966).

TM 66-38 "Fluctuating Component Measurements in the Thermo-Simulation Facility, Discussion and Preliminary Program", (1966).

TM 66-39 "Design Details for Helium Heater", (1966).

Additional notes were written on various subjects and issued as informal items for the direct attention of the engineers concerned. These covered estimated sound pressure fields in the vicinity of the hot jets, calculations to help the designers of the jet rig, and a review of the rig design.

### 3.0 NOISE FIELD OF HIGH SPEED JETS

#### 3.1 Near Field Noise Analysis

A program to study the near noise field of high speed jets involving an analytic/empirical approach has been completed. Preliminary studies have indicated the major problems are determining the source locations in the exhaust stream and the directivity of radiation of the sources. The important parameters have been determined and are used to draw up a series of experiments to provide the necessary results to solve these problems. This program must necessarily include certain correlation measurements to allow the directivity of sound radiation to be determined. The ultimate aim is a new prediction method to allow accurate estimates of near field noise.

The following report has been completed on this task:

WR 66-45 "On the Prediction of the Near Field Noise of Supersonic Jets",  
By J. B. Ollerhead (1966)

#### 3.2 Mach Wave Radiation (Shadowgraph Study)

This task involves a series of shadowgraph experiments to study the Mach wave radiation of high speed jets, and determine its importance to the sound radiated by the flow. These tests have been completed with the Marshall Space Flight Center small heater rig used to flow unheated air through a specially designed perfectly expanded nozzle. These tests have included photographs of a complete acoustic field, up to 40 diameters from the jet axis, the radiated field when the nozzle is operated with under-expanded and over-expanded flow, oblique shadowgraphs to determine the extent of the Mach waves around the jet, and the Mach waves radiated from deflected flows. The final experiment was completed by NASA on Friday, November 18, 1966.

Wyle Laboratories prepared a complete test plan, including details of the parameters to be used in the experiment, and provided consultation on the detail design of the facility. Further, Wyle Laboratories conducted a small experiment using a supersonic nitrogen jet to examine the effects of source-jet-film spacing on the shadowgraph, and to examine possible focusing effects by introducing lenses.

The final report on the Marshall Space Flight Center experiments was completed during the contract extension period. This was necessary because of the delay by NASA in concluding these experiments. It is recommended that additional experiments, including acoustic measurements and dual exposure techniques, be made. These will extend the knowledge of Mach wave propagation.

Reports issued on this task are:

- WR 67-3 "Shadowgraph Visualization of Noise from Cold Supersonic Jets," by M.V. Lowson, (1967).
- WR 66-44 "Some Shadowgraph Experiments with a Cold, Supersonic Jet," by J.B. Ollerhead, (1966).
- TM 66-15 "Shadowgraph Experiments in the Marshall Space Flight Center Jet Flow Facilities", (1966).
- TM 66-18 "Noise Field for Shadowgraph Model Rocket Experiments", (1966).
- TM 66-27 "Shadowgraph Continuation Experiments", (1966).
- TM 66-37 "Note on Shadowgraph Continuation Experiments (TM 66-27) and Program for Deflector Experiments", (1966).

A report on the Marshall Space Flight Center experiments is being prepared.

### 3.3 Acoustic Sources

An analysis of clustered rocket near field noise measurements was made to attempt to clarify the source location controversy. The results indicated the major sources to occur in the downstream flow.

The following report was issued:

- WR 66-28 "Acoustic Sources in Rocket Exhaust Flow",  
By R. C. Potter, (1966).

## 4.0 INSTRUMENTATION

### 4.1 Hot Wire Anemometer

The hot wire anemometer is the most useful available tool for studying turbulent flows. A review of the technique was prepared.

The following report was issued:

WR 64-8 "The Hot Wire Anemometer", by R. C. Potter, (1964).

### 4.2 Hot Wire Dynamic Calibration Experiments

A technique was proposed and an experiment completed to examine the possibilities of dynamically calibrating hot wire systems by moving the wire in a known fashion in a steady air stream. The experiment involved oscillating a cantilever beam, with a probe attached, by an electro-mechanical shaker. Despite the limited frequencies available, certain interesting results were obtained. It is recommended that the technique could be usefully extended to supersonic flows.

The following report was issued:

WR 66-29 "A Technique for the Dynamic Calibration of Hot Wire Anemometers", by R. C. Potter, (1966).

## 5.0 TURBULENCE STUDIES

A fundamental experiment to study the macroscale of turbulence was started. It involved the operation of eight constant-temperature hot wire anemometers to measure simultaneously eight velocity components of the turbulence in the mixing region of a subsonic cold jet. The technique is one stage beyond the basic statistical descriptions normally used, and will provide a better understanding of the nature of turbulence. Ultimately, the objective is to provide a complete description of a turbulence eddy which should help in optimizing turbulence models.

The experiment involves on-line digital data acquisition to preserve the phase relationships between the various channels. The apparatus was completed and preliminary results obtained and reported. It is recommended that this study be continued.

The following report was issued:

WR 66-46 "Program to Measure the Macroscale Turbulence of Subsonic Jets", by E. B. Miller and R. C. Potter, (1966).

## 6.0 NON-LINEAR ACOUSTICS

A study of the sound propagation in the near field, where non-linear effects occur, has been completed, based on the application of Burger's equation. The boundary condition problem has been particularly examined, and has allowed a significant advance in the theoretical approach to this problem. It is recommended that this study be continued.

The following report was issued:

WR 66-37 "Propagation of Waves of Finite Amplitude in Thermo-viscous Media", by E. Y. Rodin, (1966).

## 7.0 CONCLUDING REMARKS

The tasks completed have all been aimed at extending the knowledge of the noise generating mechanisms of supersonic jet flows, typical of rocket exhausts. As a result of the studies completed, it is recommended that certain tasks be continued.

It is concluded that the noise field of a rocket exhaust is the combined reaction of three sources. These are turbulent-shear flow noise, Mach wave radiation from the flow near the nozzle, and shock-turbulence interaction noise. As a result of the studies completed to date, some ideas on the relative magnitude of each source has been determined, and the mechanism can be tentatively described. With the results from the proposed extended studies, including the basic heated jet experiments and the acoustic-shadowgraph experiments, it should be possible to produce a refined prediction method for rocket jet noise.

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